AD-A119 402 NAVAL SURFACE WEAPONS CENTER SILVER SPRING MD F/G 11/4
THE ULTRASONIC DETECTION OF UNBOND IN DEEP LAYERS OF MULTILAYER--ETC(U)
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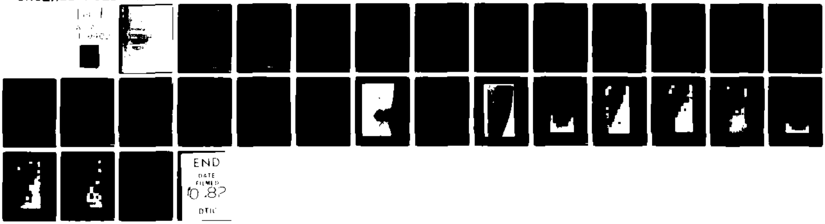

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The through transmission ultrasonic method was applied to the problem of detecting unbond in deep layers of multilayer composites. A casting containing severe internal defects was used for the base metal. A range of thickness and non-parallel surfaces were considered. Using the decibel scale, the casting was characterized on a one inch grid. From the difference between this and subsequent measurements as layers were applied, it was possible to distinguish between bond and unbond on layers well beneath

BLOCK 20. the surface.

FOREWORD

Techniques have been developed which enable a nondestructive evaluation of bond quality in deep layers of multilayer composites. The method is based on ultrasonic through transmission with prior characterization of the base material.

This work has been reviewed by Mr. Clifford W. Anderson of the Materials Evaluation Branch.

J. R. Dixon

J. R. DIXON
By direction

CONTENTS

ILLUSTRATIONS

TABLES

INTRODUCTION

For many reasons it is desirable to bond a layer or layers of material to a base material. In an application where bond integrity is of importance, there may be a need for quality assurance and a method of nondestructive testing to accomplish that purpose. Of the methods of nondestructive testing, ultrasonics offers the most promise.

ULTRASONIC THEORY

Sound waves of ultrasonic frequency propagate in solid materials (with attenuation) until reaching a boundary. A boundary constitutes an acoustic impedance mismatch and some portion of the sound energy will be reflected while the remainder will be transmitted across the boundary. The relative proportions of reflection and transmission are determined by the degree of acoustic impedance mismatch. Generally speaking, reflection is more pronounced with higher frequencies.

The reflection of sound waves at a boundary is the basic principle of ultrasonics as a tool of nondestructive testing. In normal applications, the reflected sound wave is analyzed to derive quantitative information related to the boundary where reflection took place. Frequencies above 1 MHz are generally used and the most common boundary is an air gap. For these conditions, reflection is virtually total and consequently there is little interest in the transmitted portion of the sound wave.

In the case of a simple composite involving only one boundary, reflection off that boundary is a viable approach; but for multiple layer composites, those boundaries deeper than the first beneath the surface cannot be examined utilizing the reflected sound wave.

The portion of the sound wave transmitted across the boundary offers another approach. Although an epoxy bonded surface will reflect much of the sound impinging upon it, a measurable amount of transmission does take place, especially at frequencies of 1 MHz and below. Unfortunately, there is a "kissing bond" problem where two surfaces have been wetted with epoxy and then the epoxy has been allowed to cure before the surfaces are pressed together. It has been found that at such low ultrasonic frequencies some transmission also occurs in this situation. Consequently, the ordinary go-no go type of test is not possible; instead, it will be necessary to distinguish between proper bond and "kissing bond."

From an ultrasonic standpoint, the problem is that the amount of sound transmitted through the composite is affected not only by the degree of bond, but also by inhomogeneities in the materials. In order to circumvent the problem of a material containing inhomogeneities using through transmission, it is necessary to characterize the material before it is bonded. A quantitative determination of the sound transmitted through the material at a series of points must be made. The sound transmission will then be redetermined after applying a layered structure. The difference in sound transmission can then be determined by subtracting one transmission amplitude from the other.

THE TEST OBJECT

The base metal selected for this study is a casting. This is because the proposed approach must consider inhomogeneities in the base material that would affect the transmission of sound. A thick casting can be expected to contain inhomogeneities; and Figure 1, which is a reproduction of a negative of a radiograph of the casting, bears this out.

Slag or laminations would also represent the condition but these are difficult to create in controlled amounts.

If the application is to be universal, non-parallel surfaces and non-uniform thicknesses must be considered. These conditions were incorporated into the test object by machining one surface smooth and plane while machining the opposite surface at a 24-inch radius. This provided a thickness changing from 8 1/2" to 4 1/2" and a changing deviation from the parallel surfaces condition.

A multilayered test specimen was fabricated by epoxy bonding a series of alternating non-metallic and metallic layers to the flat surface of the casting. In order to provide a sample of an unbonded interface, one diagonal half of the first interface between the non-metallic layer and the casting contained hardened epoxy on each surface, but no bond between the surfaces, Figure 2. The other diagonal half of the layer and a narrow perimeter around the outside edge of the layer were properly bonded. The subsequent three layers consisting of a metallic, a non-metallic, and finally a metallic layer were all properly bonded to the specimen. Figure 3 is a photograph of the completed test object.

EXPERIMENTAL PROCEDURE

Prior to test specimen construction, a one inch grid was scribed over the flat surface of the casting. A projection of the flat surface grid was then scribed on the opposite curved side of the casting. By introducing sound into the object on the planar surface, one could easily follow the grid lines on the curved surface to correctly position the receiving transducer.

When subsequent layers were added to the plane surface, the grid was reconstructed and the transducers were again correctly positioned as before. For the above test object, there are 108 test locations.

Ultrasonic through-transmission measurements were made for the following conditions:

A. Bare casting (after machining) 0.5 MHz and 1.0 MHz;

B. Condition 1 - one layer flexible non-metallic material 0.5 MHz and 1.0 MHz;

C. Condition 2 - the addition of layer of wrought metal 0.5 MHz and 1.0 MHz;

D. Condition 3 - the addition of another layer of flexible non-metallic material and another layer of wrought metal. 0.5 MHz

Attempts to apply 1.0 MHz to Condition 3 were unsuccessful due to both transducer driving and amplification limitations with the available ultrasonic equipment.

The measurement of sound transmission are expressed in decibels which is a relative logarithmic ratio. The portion of the decibel scale applicable to this work is reproduced in Table 1 below.

TABLE 1 DECIBEL VS AMPLITUDE RATIOS

dB vs. Amplitude Ratio Chart			
dB	Ratio	dB	Ratio
0	1.00:1	11	3.55:1
0.5	1.06:1	12	3.98:1
1	1.12:1	13	4.47:1
2	1.26:1	14	5.01:1
3	1.41:1	15	5.62:1
4	1.58:1	16	6.31:1
5	1.78:1	17	7.08:1
6	2.00:1	18	7.94:1
7	2.24:1	19	8.91:1
8	2.51:1	20	10.00:1
9	2.82:1	40	100.00:1
10	3.16:1	60	1000.00:1

EXPERIMENTAL FINDINGS

The experimentally determined sound transmissions for the conditions considered are presented in Tables 2-8. Referring to the decibel scale, a difference of 6 dB between two readings is a factor of 2 difference in signal amplitude of those two locations. By the same token, a difference of 12 dB is a factor of 4, while a difference of 18 dB relates to a factor of eight. From the data in Tables 3-8 it can be seen that the unbonded area is detected, even for the four layer condition.

As expected, the "contrast" between bond and unbond is somewhat greater at 1 MHz but the evaluation of 0.5 MHz is satisfactory and reliable.

Recognizing that the data presented in Tables 2-8 would be easier to interpret if presented in pictoral form, a computerized presentation is set forth in Figures 4-10. Each square relates to a single measurement on the one inch grid. The degree of darkening of a square is proportional to the difference in dB obtained at that point and the dB level through the bare casting.

CONCLUSIONS

From the analysis presented in this report, the authors conclude that lack of bond in multilayer composites can be reliably detected using through transmission ultrasonics providing the base metal is first ultrasonically characterized.

TABLE 2. ULTRASONIC TRANSMISSION THROUGH THE BARE CASTING, .5 MHz, DECIBELS

H	35	39	43	45	47	49	57	54	55	64	61	62	64	63	63	63
G	38	42	45	60	55	63	63	61	55	59	64	63	65	56	67	72
F	40	51	60	58	69	60	58	61	54	52	59	65	69	66	59	62
E	43	51	69	74	72	74	66	58	65	62	57	67	59	64	70	60
D	43	49	68	76	81	66	60	66	61	60	60	65	62	56	68	66
C	39	50	63	66	63	64	62	56	55	55	51	58	56	68	58	61
B	38	44	49	62	66	69	58	67	57	56	53	61	62	56	64	53
A	35	38	48	46	50	53	54	56	56	55	55	54	65	68	67	65
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

TABLE 3. CONDITION 1 MINUS CASTING AT .5 MHz, DECIBELS

H	17	18	14	18	15	14	12	18	10	18	14	22	13	9	11	14
G	5	6	25	35	37	28	39	32	40	39	39	37	37	34	26	7
F	10	8	3	14	15	29	28	41	47	42	41	40	32	38	42	20
E	4	6	7	4	7	10	14	27	33	33	45	36	42	38	32	27
D	3	6	7	29	7	8	6	4	15	35	39	37	41	37	36	15
C	5	5	6	6	6	8	7	12	4	13	14	32	36	29	34	25
B	5	6	6	2	3	0	5	4	6	3	8	11	8	25	38	17
A	8	7	2	5	3	5	7	4	8	7	9	11	2	4	8	8
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

TABLE 4. CONDITION 2 MINUS CASTING AT .5 MHz, DECIBELS

H	22	18	16	30	30	26	31	37	27	21	27	23	20	8	14	17
G	26	18	26	22	28	26	27	29	35	32	31	31	24	30	20	11
F	11	5	9	11	9	27	24	32	36	43	40	31	29	23	29	19
E	6	6	0	1	3	11	13	23	17	26	40	27	37	30	22	24
D	7	8	2	5	0	7	8	5	12	23	26	22	32	31	22	14
C	8	6	8	7	8	9	11	18	9	11	22	23	28	21	30	16
B	12	9	9	7	5	3	8	4	7	11	16	15	12	29	20	17
A	9	9	6	10	7	10	11	8	9	9	8	14	4	12	8	9
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

TABLE 5. CONDITION 3 MINUS CASTING AT .5 MHz, DECIBELS

H	34	32	33	39	38	35	929	932	31	922	925	24	21	18	22	21
G	28	25	27	22	29	23	923	925	31	927	922	923	21	29	16	14
F	17	13	17	17	15	26	918	925	932	34	927	921	917	920	927	23
E	16	15	3	8	10	12	18	24	18	22	929	919	927	922	16	24
D	16	17	7	7	0	15	18	13	22	23	26	921	924	30	918	18
C	17	15	10	8	12	11	18	18	20	21	27	23	29	918	28	25
B	16	18	16	10	10	7	16	10	16	21	26	21	21	25	19	25
A	19	18	14	17	17	20	19	19	17	18	16	22	14	14	13	19
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

TABLE 6. TRANSMISSION IN DECIBELS, BARE CASTING AT 1 MHz

H	0	4	10	15	18	20	29	24	28	37	32	34	40	42	38	31
G	3	8	17	22	33	36	31	24	33	38	40	34	34	31	40	45
F	6	18	29	36	40	44	39	34	30	27	29	43	41	41	39	41
E	10	25	44	51	46	48	40	32	39	32	32	40	30	39	38	32
D	10	25	43	963	963	46	41	39	36	35	45	36	38	35	48	40
C	10	28	41	43	39	40	37	28	26	28	26	31	32	38	28	43
B	5	18	23	36	35	38	32	35	34	26	33	32	35	28	35	28
A	6	7	14	23	25	27	28	29	34	30	31	33	43	39	41	44
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

TABLE 7. CONDITION 1 MINUS CASTING AT 1 MHz, DECIBELS

H	28	16	17	23	24	12	10	21	14	14	24	17	11	4	10	14
G	7	17	19	33	28	21	29	25	25	26	24	31	31	30	18	9
F	5	8	9	15	17	12	21	23	30	31	37	23	24	24	23	12
E	4	4	8	0	10	9	15	23	27	21	34	25	32	25	27	28
D	3	6	12	-905	-904	9	4	5	10	29	20	29	27	25	18	4
C	0	1	5	4	7	5	5	6	11	11	16	28	29	22	33	7
B	5	2	6	5	7	6	5	5	3	5	8	10	9	26	27	15
A	1	6	5	4	7	8	7	7	2	8	5	8	5	9	6	5
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

TABLE 8. CONDITION 2 MINUS CASTING AT 1 MHz, DECIBELS

H	24	23	19	29	33	31	27	932	928	919	924	922	16	9	10	17
G	34	24	27	33	32	38	925	932	923	918	916	922	922	925	916	9
F	9	17	14	10	14	30	917	922	43	929	927	913	915	915	917	13
E	9	10	3	3	7	12	13	20	17	924	924	916	926	917	918	22
D	6	11	7	-903	-908	3	4	11	12	21	911	920	918	921	908	10
C	7	9	7	8	7	13	9	12	13	12	22	25	924	918	928	8
B	8	8	8	11	8	13	10	11	7	14	12	19	16	27	921	21
A	4	8	9	6	10	12	14	13	8	10	8	13	0	15	10	6
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

FIGURE 1. PHOTOGRAPHIC NEGATIVE OF A RADIOGRAPH OF THE CASTING USED IN THE TEST OBJECT

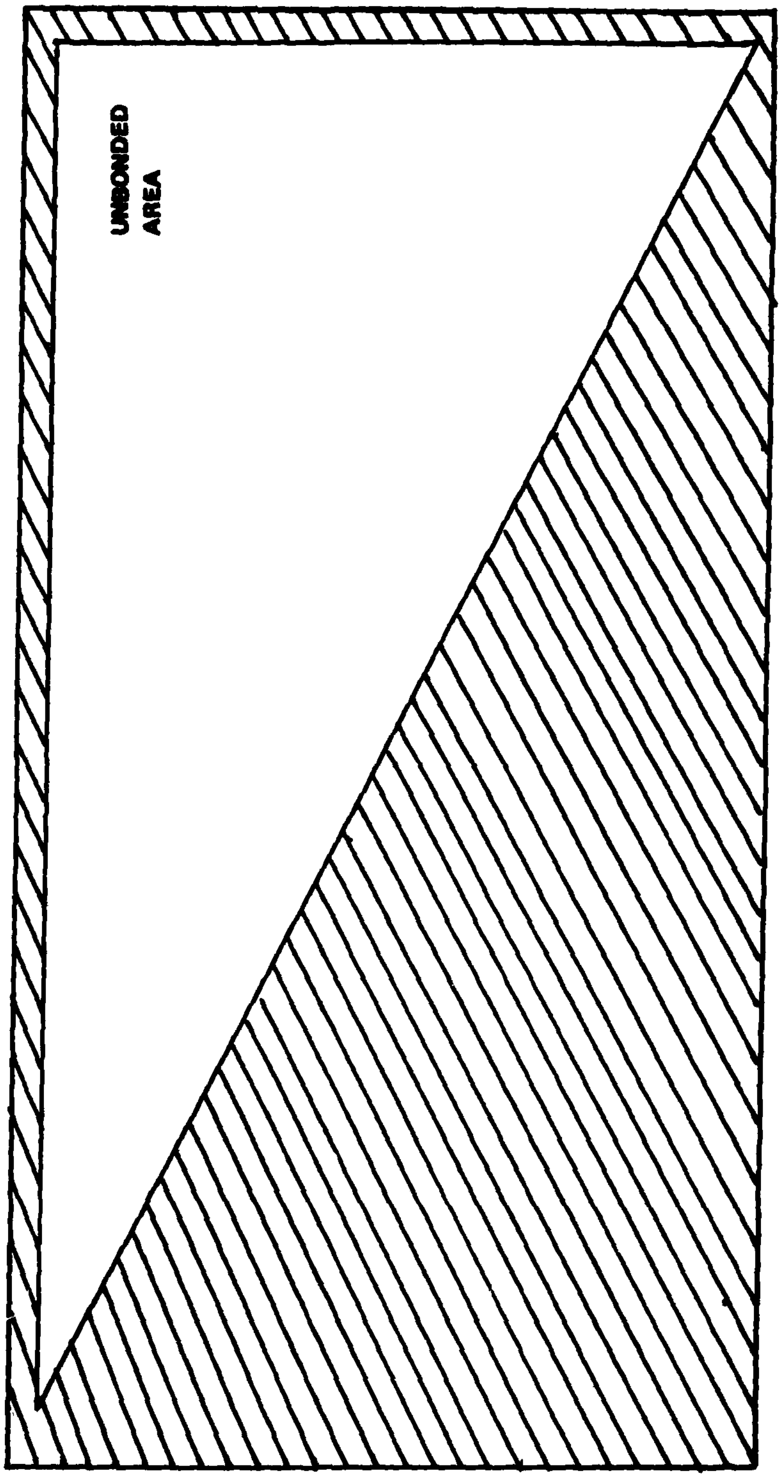

FIGURE 2. SCHEMATIC OF BOND-UNBOND INNERMOST BOUNDARY OF THE TEST OBJECT

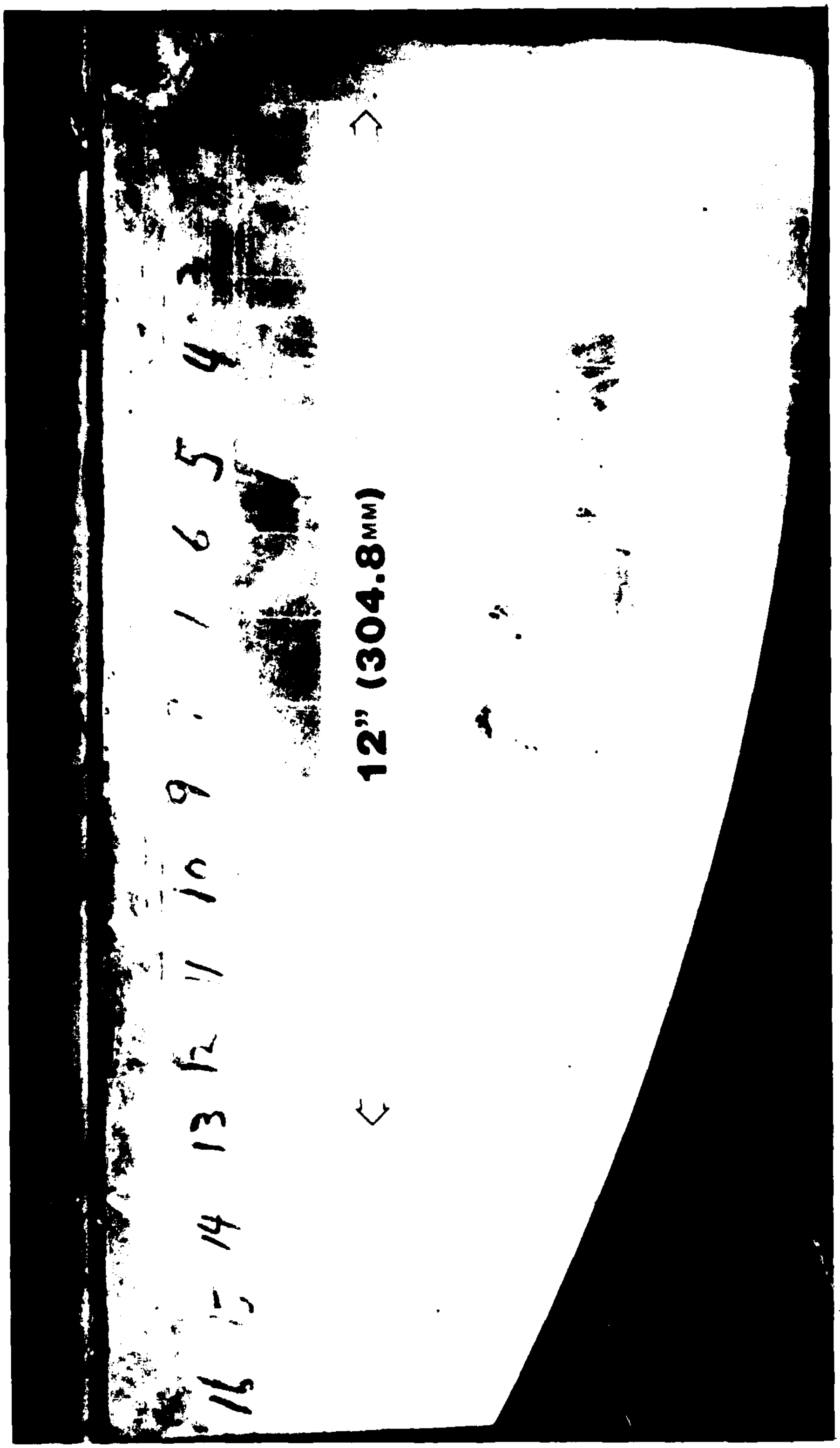

FIGURE 3. THE TEST OBJECT

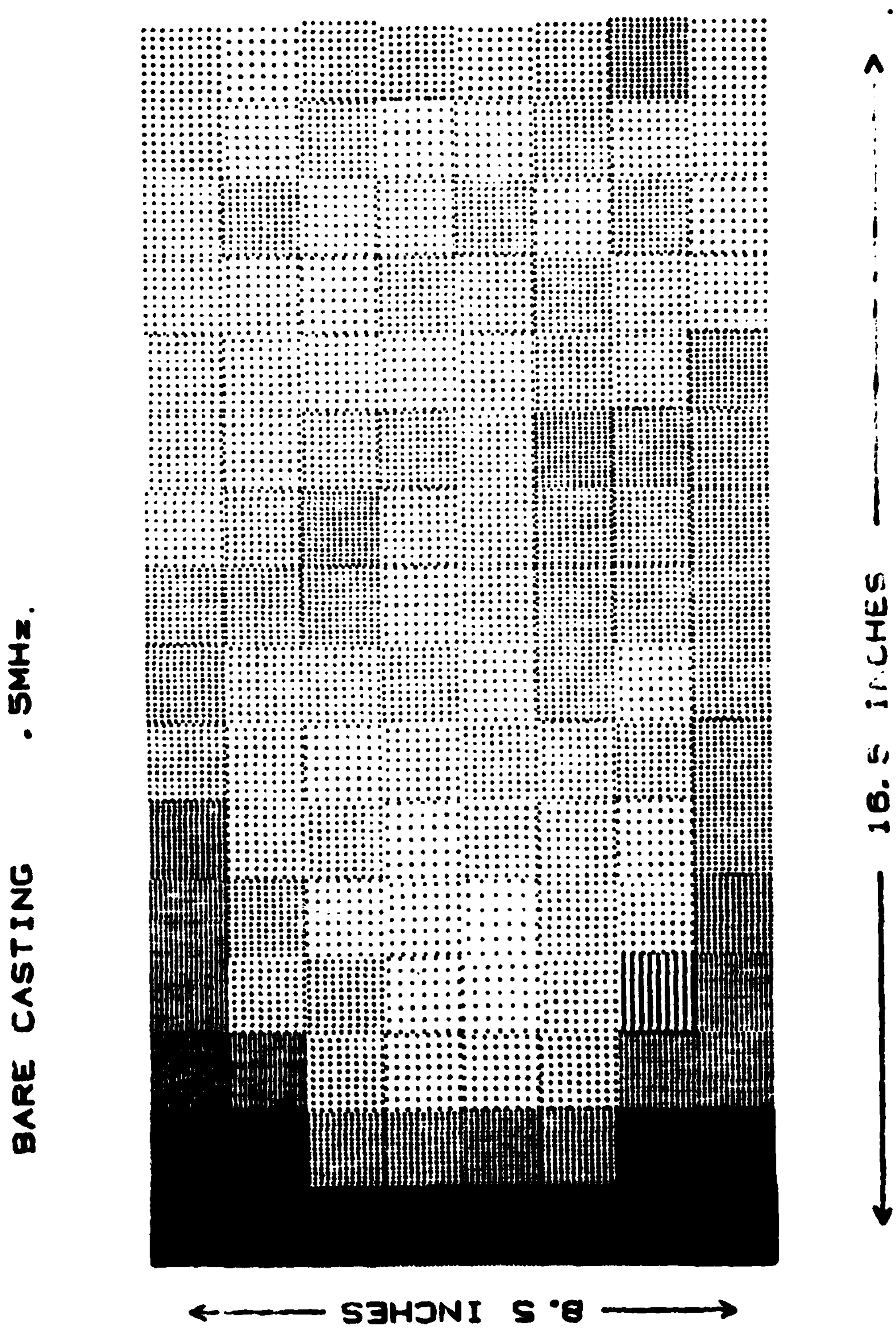

FIGURE 4. ULTRASONIC TRANSMISSION THROUGH THE BARE CASTING, .5 MHz

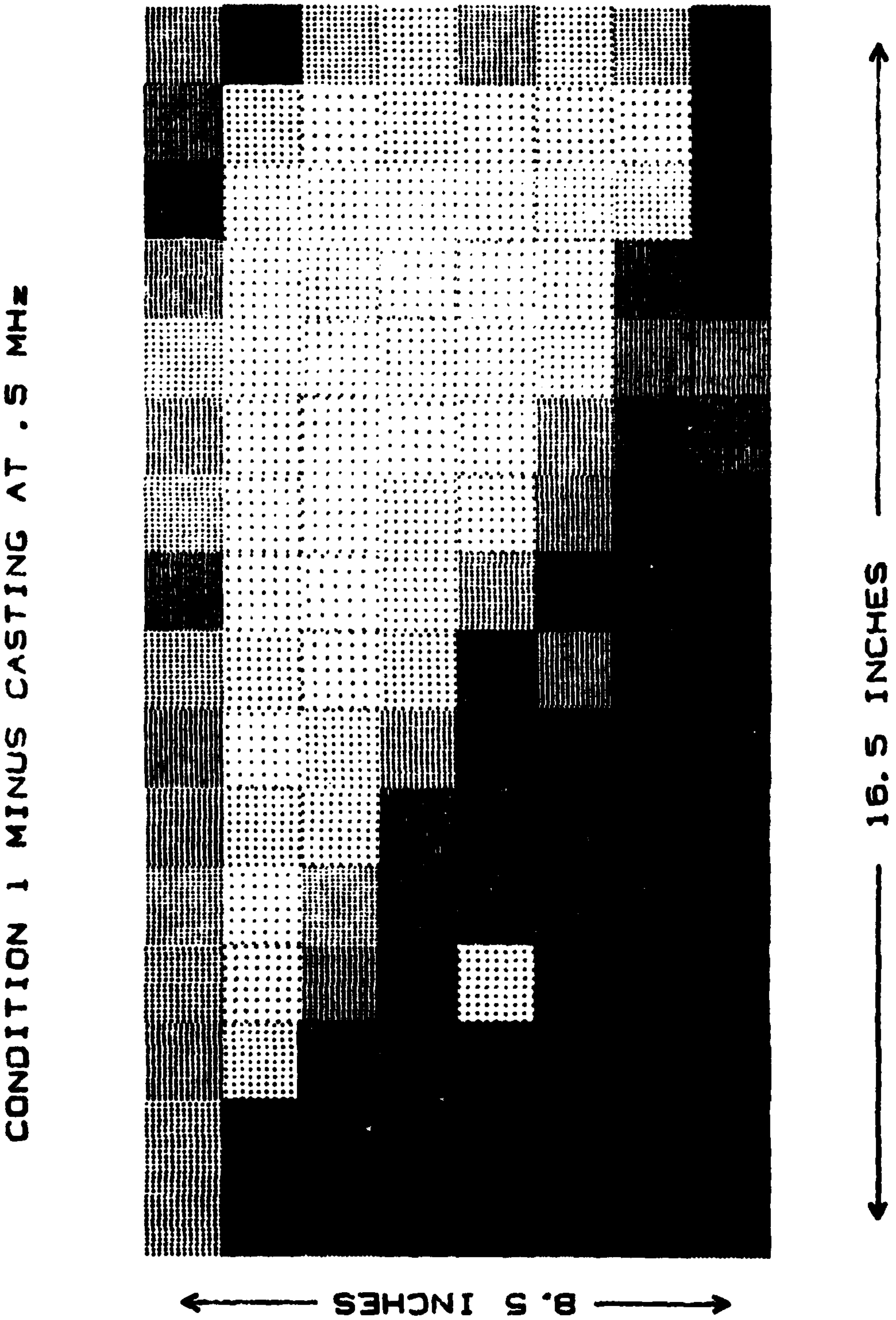

FIGURE 5. ULTRASONIC TRANSMISSION, CONDITION 1 MINUS THE BARE CASTING, .5 MHz

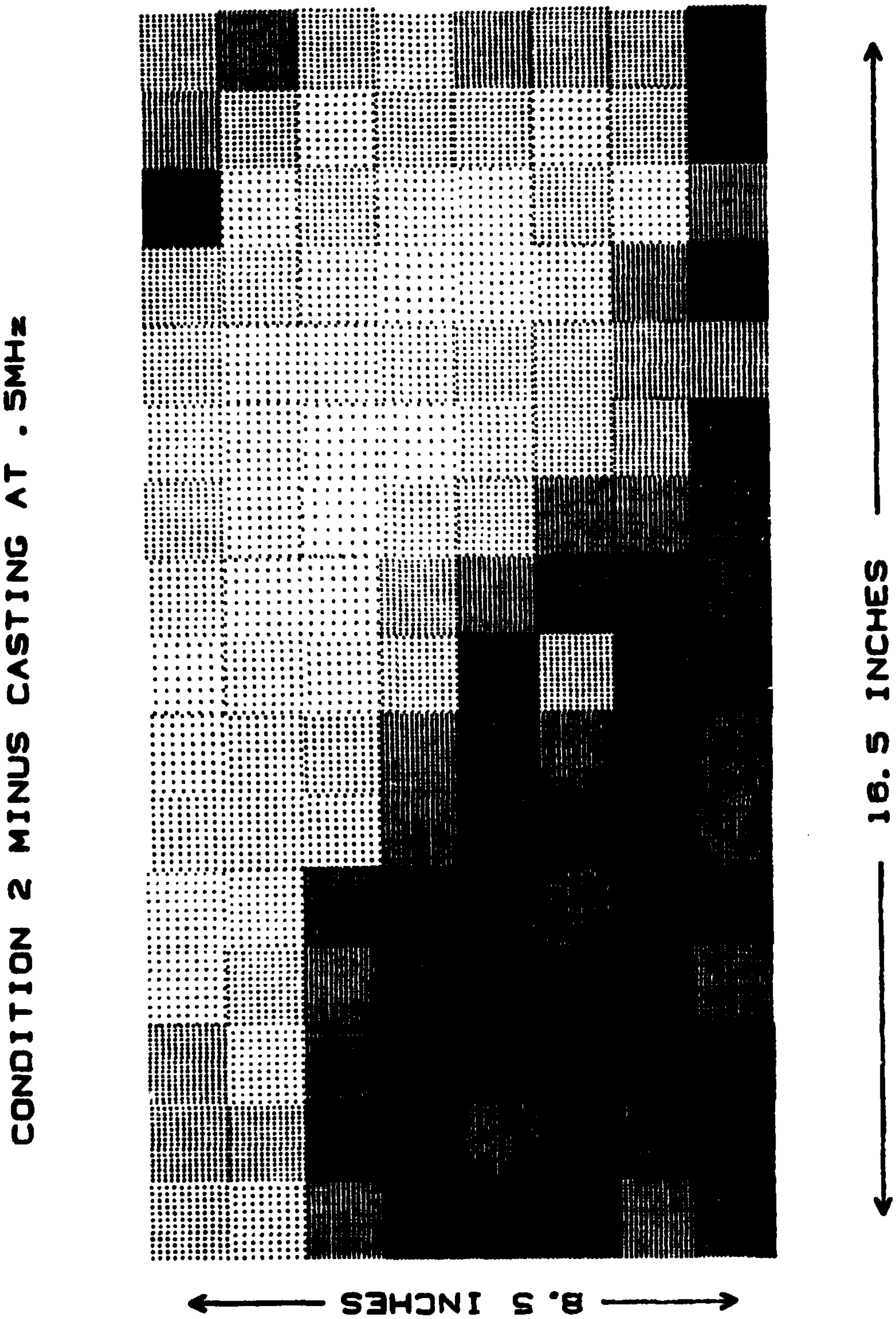

FIGURE 6. ULTRASONIC TRANSMISSION CONDITION 2 MINUS THE BARE CASTING ,.5MHz

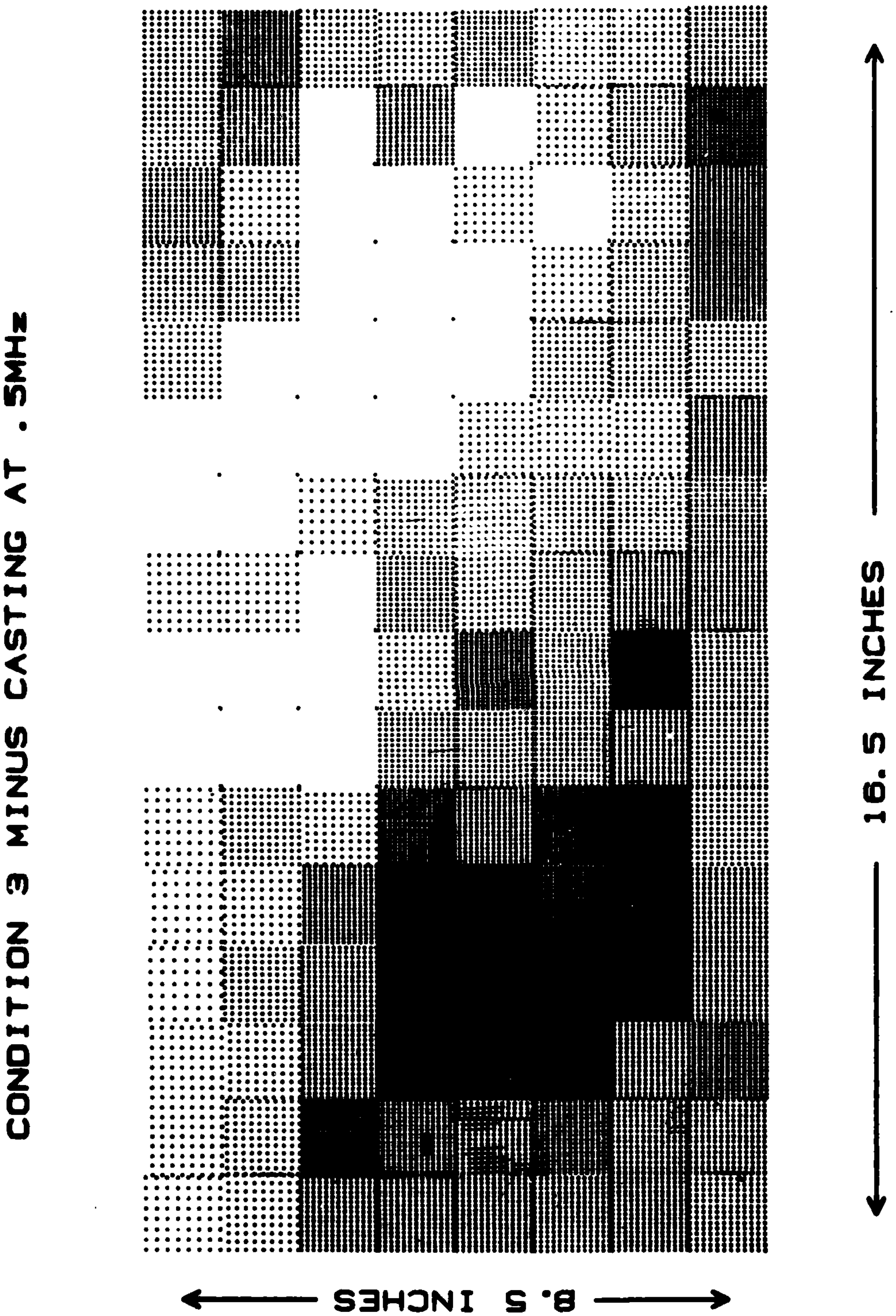

FIGURE 7. ULTRASONIC TRANSMISSION, CONDITION 3 MINUS THE BARE CASTING, .5 MHz

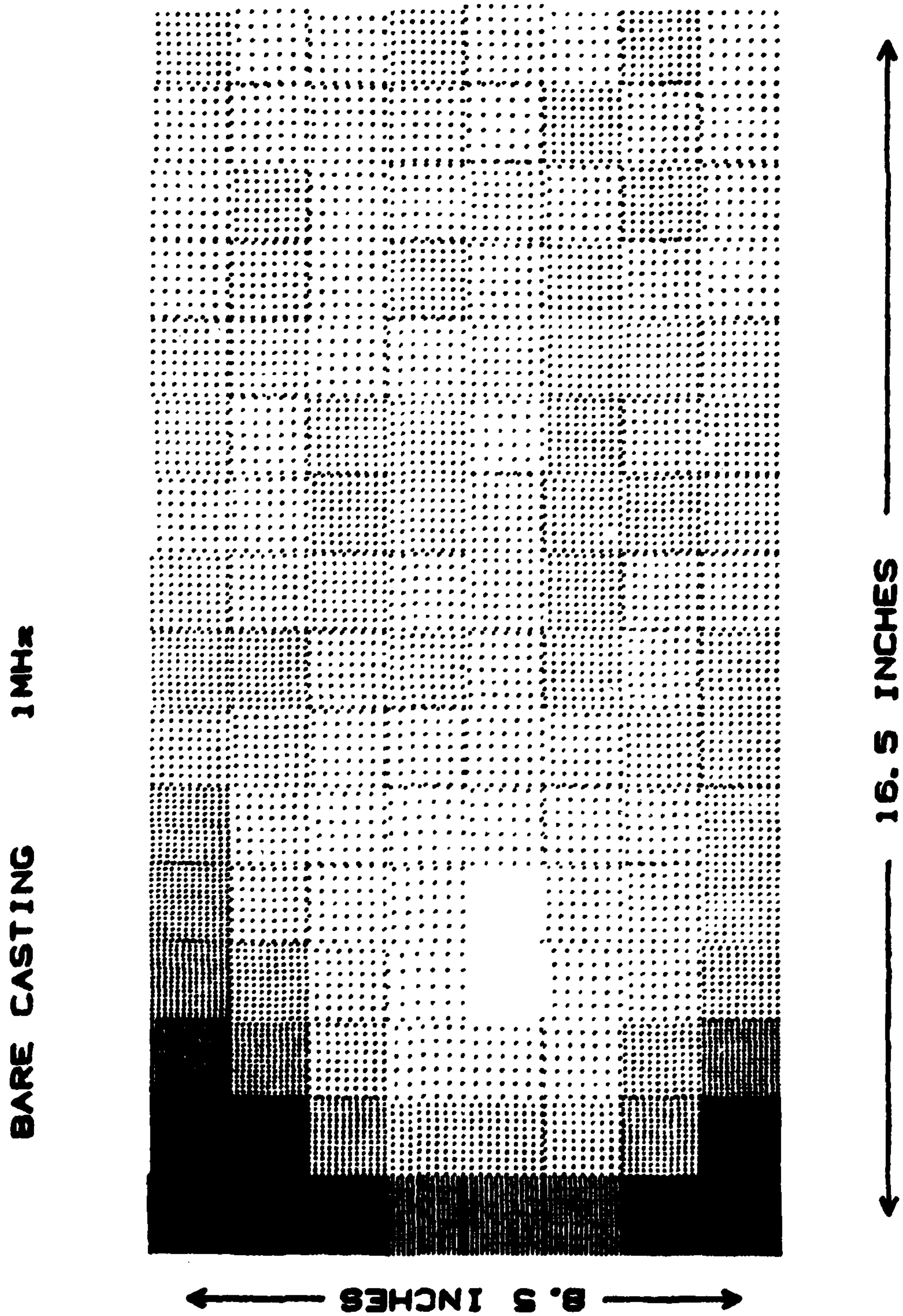

FIGURE 8. ULTRASONIC TRANSMISSION THROUGH THE BARE CASTING, 1.0 MHz

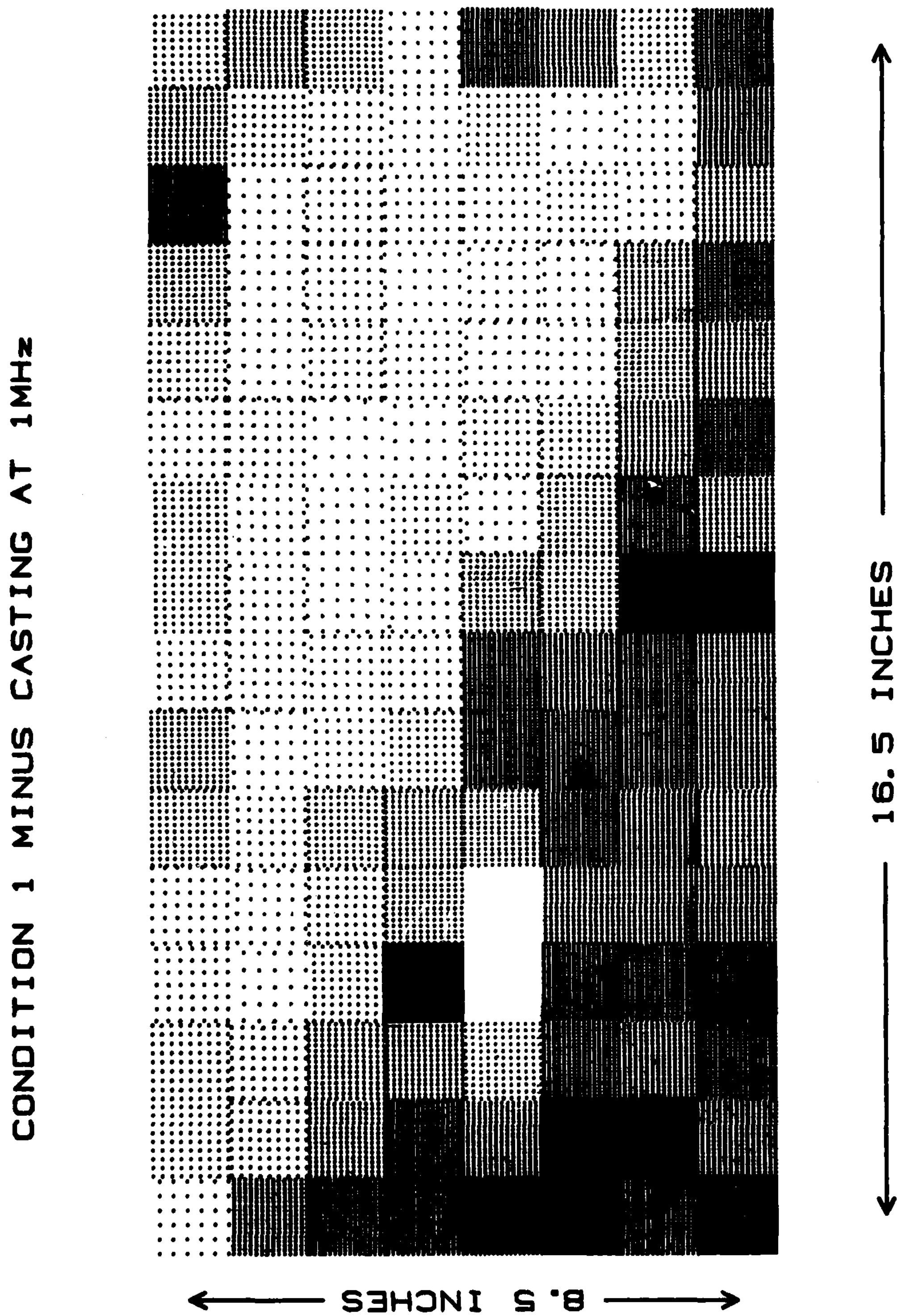

FIGURE 9. ULTRASONIC TRANSMISSION, CONDITION 1 MINUS THE BARE CASTING, 1.0 MHz

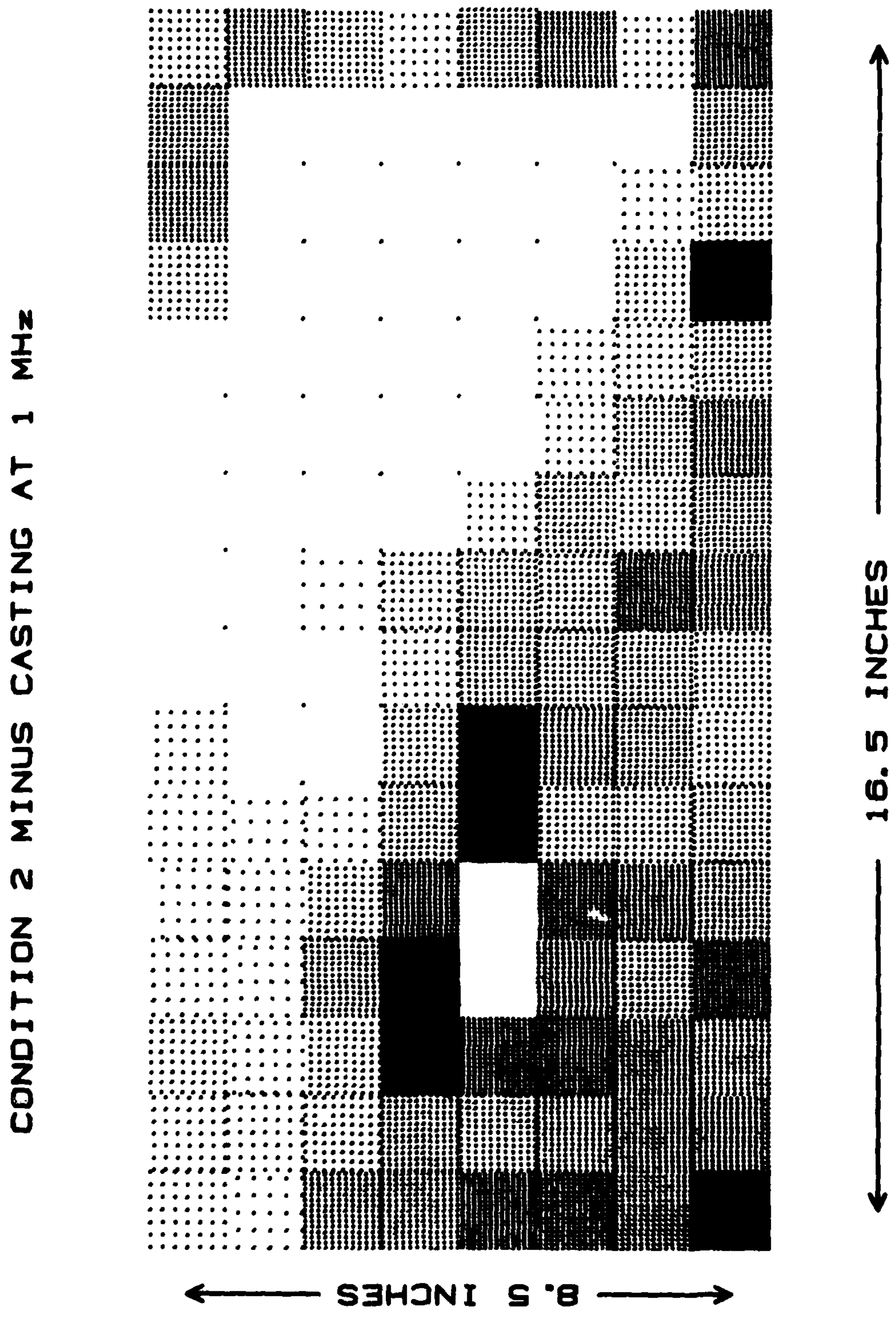

FIGURE 10. ULTRASONIC TRANSMISSION, CONDITION 2 MINUS THE BARE CASTING, 1.0 MHz

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